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Copper-silver ionization at a US hospital: Interaction of treated drinking water with plumbing materials, aesthetics and other considerations

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ABSTRACT

Tap water sampling and surface analysis of copper pipe/bathroom porcelain were performed to explore the fate of copper and silver during the first nine months of copper-silver ionization (CSI) applied to cold and hot water at a hospital in Cincinnati, Ohio. Ions dosed by CSI into the water at its point of entry to the hospital were inadvertently removed from hot water by a cation-exchange softener in one building (average removal of 72% copper and 51% silver). Copper at the tap was replenished from corrosion of the building's copper pipes but was typically unable to reach 200 μg/L in first-draw and flushed hot and cold water samples. Cold water lines had >20 μg/L silver at most of the taps that were sampled, which further increased after flushing. However, silver plating onto copper pipe surfaces (in the cold water line but particularly in the hot water line) prevented reaching 20 μg/L silver in cold and/or hot water of some taps. Aesthetically displeasing purple/grey stains in bathroom porcelain were attributed to chlorargyrite [$AgCl_{(s)}$], an insoluble precipitate that formed when CSI-dosed Ag^{+} ions combined with Cl^{-} ions that were present in the incoming water. Overall, CSI aims to control *Legionella* bacteria in drinking water, but plumbing material interactions, aesthetics and other implications also deserve consideration to holistically evaluate in-building drinking water disinfection.

1. Introduction

Hospitals in the United States (US) and world-wide are increasingly relying on in-building disinfection to control waterborne pathogens (e.g., *Legionella pneumophila*, *Mycobacterium avium* and *Pseudomonas aeruginosa*) and ultimately prevent or mitigate disease outbreaks in sensitive patients (Falkinham et al., 2015; Pruden et al., 2013). Systemic drinking water disinfection options for buildings include free chlorine, chlorine dioxide, monochloramine, UV radiation, ozone and copper silver ionization, with each option having different presumed or proven limitations and benefits (Rhoads et al., 2015; Pruden et al., 2013; Lin et al., 2011, 1998).

The implications of in-building water treatment are not fully understood (Rhoads et al., 2015, 2014). Information is gradually being collected as more disinfection technologies become commercially available, as buildings increasingly install such systems, and as researchers, policy-makers, building managers, manufacturers and water consumers assess the full impact of such installations on water quality. During a 2013 US Environmental Protection Agency (EPA) workshop, US state representatives requested more research on the effectiveness of each disinfection treatment against *Legionella* and on water quality evaluation after in-building disinfection is applied (Triantafyllidou et al., 2014).

Given that the primary objective of water disinfection in buildings is pathogen control, it is not surprising that its impact on general water chemistry and other potential consequences are often overlooked. But as with any type of water treatment, interactions of added disinfectants with the incoming water chemistry and with building plumbing materials can have other important effects (e.g., formation of disinfection byproducts and/or metallic corrosion) which could compromise the integrity of the

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plumbing system and even impact the efficacy of disinfection itself (Rhoads et al., 2015, 2014). In addition, possible aesthetic issues (water/fixture discoloration, taste or odor) arising from in-building drinking water treatment may shape public perception of its effectiveness, whether they constitute sensory nuisances or true health threats (Dietrich, 2006). Assessment of in-building water disinfection should therefore include water chemistry impacts (non-microbiological) and public perception (aesthetics).

The efficacy of copper-silver ionization (CSI) to control *Legionella* in building plumbing systems has been studied, but little information has been gathered on water quality impacts, aesthetics and other factors associated with CSI installations. Most CSI case studies have been in hospitals or nursing homes, where only the hot water was treated and where treatment efficacy was based on microbiological indicators. Study findings have been mixed, with several reporting positive results of CSI in controlling *Legionella* (Dziewulski et al., 2015; Stout and Yu, 2003; Lin et al., 1998, 2002) while others did not have success (Demirjian et al., 2015; Rohr et al., 1999; CDC, 1997; Blanc et al., 2005). The reasons for this discrepancy were thought to include the development in *Legionella* of resistance to the disinfecting ions or inadequate ion concentrations (e.g., Rohr et al., 1999; Lin, 2000; Blanc et al., 2005).

CSI relies on the synergistic disinfecting capabilities of positively charged cupric ions (Cu^{+2}) and silver ions (Ag^{+}) (States et al., 1998; Lin et al., 1998). It consists of one or more flow cells, each equipped with two sacrificial copper:silver electrodes (Fig. 1). The composition of the two electrodes (i.e., copper:silver ratio) can be customized. It is typically set to 70:30 copper:silver (weight %), but other ratios have also been reportedly used in various countries (i.e., 50:50, 60:40, 70:30 and 90:10) (Walraven et al., 2015). A direct electric current is applied across the electrodes to stimulate continual release of cupric ions and silver ions into the flowing water, causing the electrodes to be gradually consumed (Fig. 1) and thus have to be replaced periodically.

In a CSI system the electric current can be adjusted through a controller, depending on water flow rate and condition of the electrodes, in order to achieve the manufacturer's recommended levels in water of 300–800 μg/L copper (optimum of 400 μg/L), and 30–80 μg/L silver (optimum of 40 μg/L) (Liquitech, Inc, 2014). Aside from this manufacturer's 2014 operations manual, some of the relevant scientific literature (e.g., Lin et al., 2011, 1998) as well as older manufacturer instructions as reported by States et al. (1998), report efficacy of CSI in controlling *Legionella* at even lower dosed minimum concentrations of 200 μg/L copper and 20 μg/L silver.

Reported operational advantages of CSI include relatively low installation/maintenance cost (Lin et al., 1998), relatively easy installation/maintenance (Lin et al., 1998) with no reagents or complex monitoring (Swertfeger and Haensel, 2014), and introduction to tap water of two metallic ions that are not expected to form disinfection byproducts (Swertfeger and Haensel, 2014). Reported disadvantages of CSI include maintenance requirement to regularly remove accumulated scale from the electrodes (States et al., 1998; Lin et al., 1998), the possibility for ion deposition onto metallic pipes causing deposition corrosion (Pruden et al., 2013; Clark et al., 2011), possible interference of the background water chemistry (in particular of water pH > 8.5) with the disinfecting ability of the added ions (Stout and Yu, 2003; Lin et al., 2002), and lavender discoloration of porcelain sink surfaces, and/or blackish discoloration of water if excessive ions are released into the water (Stout and Yu, 2003; Lin et al., 1998; States et al., 1998). Discoloration was believed to have occurred at the initial stages of CSI on surveyed hospitals' hot water lines, when silver ions exceeded the range of 20–40 μg/L (Stout and Yu, 2003). But aside from this survey result (Stout and Yu, 2003) or from brief qualitative descriptions of aesthetic problems in passing (Lin et al., 1998; States et al., 1998), the discoloration/staining issue has not been thoroughly examined in the peer-reviewed literature.

This work investigated copper and silver levels generated by CSI and distributed spatially at a large hospital in Cincinnati, Ohio applying CSI to un-softened cold and softened hot water. This hospital offered a unique opportunity to obtain a range of information relevant to CSI applications, because CSI was applied for cold water disinfection in addition to hot water disinfection, because the incoming water has a chemistry of elevated pH and hardness, and because early access to the hospital allowed pre- and post-CSI comparisons. The interaction of dosed metals with hot and cold copper pipe surfaces and with bathroom porcelain surfaces were evaluated for the first time in a CSI installation, and the source of aesthetic implications was also examined for the first time.

2. Materials and methods

2.1. Incoming drinking water, CSI treatment and ohio environmental protection agency monitoring requirements

The hospital is centrally located within the city of Cincinnati's main distribution system and receives water from an adjacent water main. The hospital receives treated surface water of elevated pH (~8.6) and moderate alkalinity (~73 mg/L $CaCO_3$) that is considered hard (~128 mg/L $CaCO_3$) after conventional treatment followed by granular activated carbon filtration, free chlorine addition (~1.2 mg/L) and polyphosphate scale inhibitor addition (sodium hexametaphosphate at ~0.16 mg/L as P) at the Miller treatment plant (GCWW , 2014).

The hospital has two multi-floor patient buildings (designated as buildings A and B) and applied CSI treatment in February 2014 (i.e., 2/14) to both hot and cold water lines throughout these buildings. Three CSI cells were installed to treat the incoming drinking water (~0.11 million gallons/day for buildings A and B) at the point of entry (Fig. 1). After passing through the CSI cells, water

Fig. 1. Three Copper-Silver Ionization (CSI) cells with three corresponding controllers (left) treated incoming water intended for both hot and cold uses. Inside a CSI cell with "fresh" (unused) 70% Cu–30% Ag electrodes (middle). Inside a CSI cell with used electrodes (right).